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13-16 August, 2001

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Little Rock, AR

MEMS Safety and Arming Device for OICW

US Army TACOM ARDEC
Fuze Division, AMSTA-AR-CCF-A
Adelphi, Maryland
301-394-0754

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Abstract	
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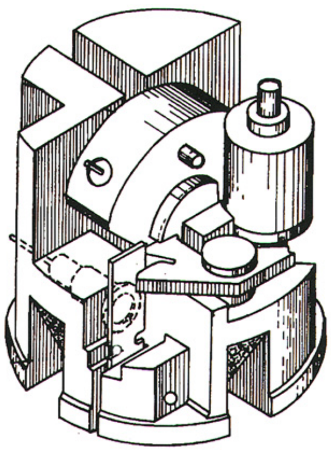
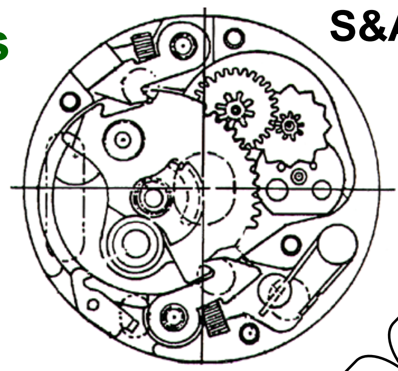
Insertion of MEMS Technology

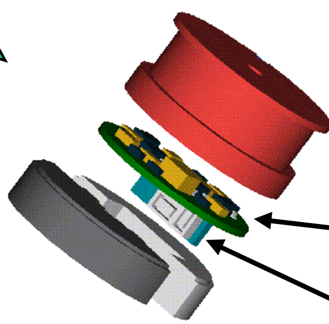
Conventional Mechanical S&As





Incorporate the functions of a conventional mechanical S&A in a single S&A die integrated with a fuze circuit.

A MEMS mechanical S&A is not a “sensor” per se. Rather, its components intrinsically combine both sense and actuate functions in a single unpowered chip.



MEMS S&A Team

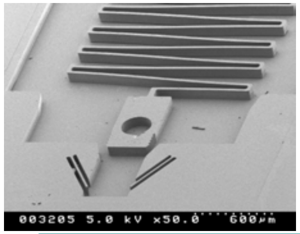
- **PM Small Arms - Customer**
- **JSSAP - Program Sponsor**
  - → OICW System Enhancements STO (Tech Base Funding)
- **Engineering Development**
  - → TACOM ARDEC Fuze Division, technical and project lead
  - → China Lake, explosive train (MSF) development
  - → WECAC, MSF producibility
  - → ARL, engineering and test support
  - → Alliant Technology, test hardware

MEMS Mechanical S&A

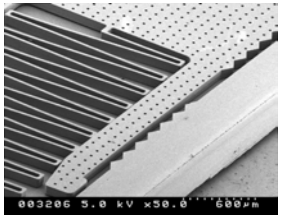
- **Goal - Demonstrate the Feasibility of:**
  - → MEMS mechanical S&A device for 20-mm OICW weapon system, with
  - → A compatible MEMS-scale firetrain (MSF)
- **Why OICW?**
  - → Reduce cost, weight, volume of S&A (increase lethality)
- **Why MEMS? (micro-electro-mechanical systems)**
  - → Robust in high-G environments---due to scaling laws
  - → Economies of high-volume production---via semiconductor industry
  - → High-accuracy miniaturization---feature resolution of 0.5 μm (0.02 mil)
  - → Readily integrated with fuze electronics---sandwich CMOS with MEMS chip
  - → Similar mechanical S&A architecture for many weapon systems
  - → Implement design changes via optical mask versus retooling production line

Technical Approach

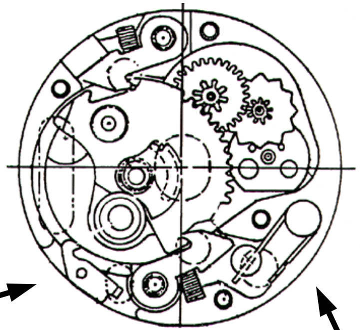
- Concept, design, analysis
  - → MEMS "inertial mechanical logic," two *inertial* locks, one *command* lock
  - → Map S&A functions to planar domain
  - → Firetrain is offshoot of NAWC-CL 'smart detonator" technology
- Fabricate MEMS test structures and S&A prototypes
  - → Inertial (zig-zag) delays, sliders, springs, locks, latches, anchors, rotors
  - → Need "high-aspect-ratio" to transport meaningful amount of energetics
    - **LIGA** (Deep X-Ray Lithography), 50-200-micron, Nickel features
    - **DRIE** (Deep Reactive Ion Etching), 80-300-micron, Silicon features
  - → Distinct from "low-aspect-ratio" multi-layer processes such as Sandia's
- Demonstration Tests:
  - → Bench demonstration of a MEMS-scale firetrain
  - → Flight demonstration of MEMS S&A hardware in Sept '01



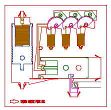
Enabling Technology: MEMS



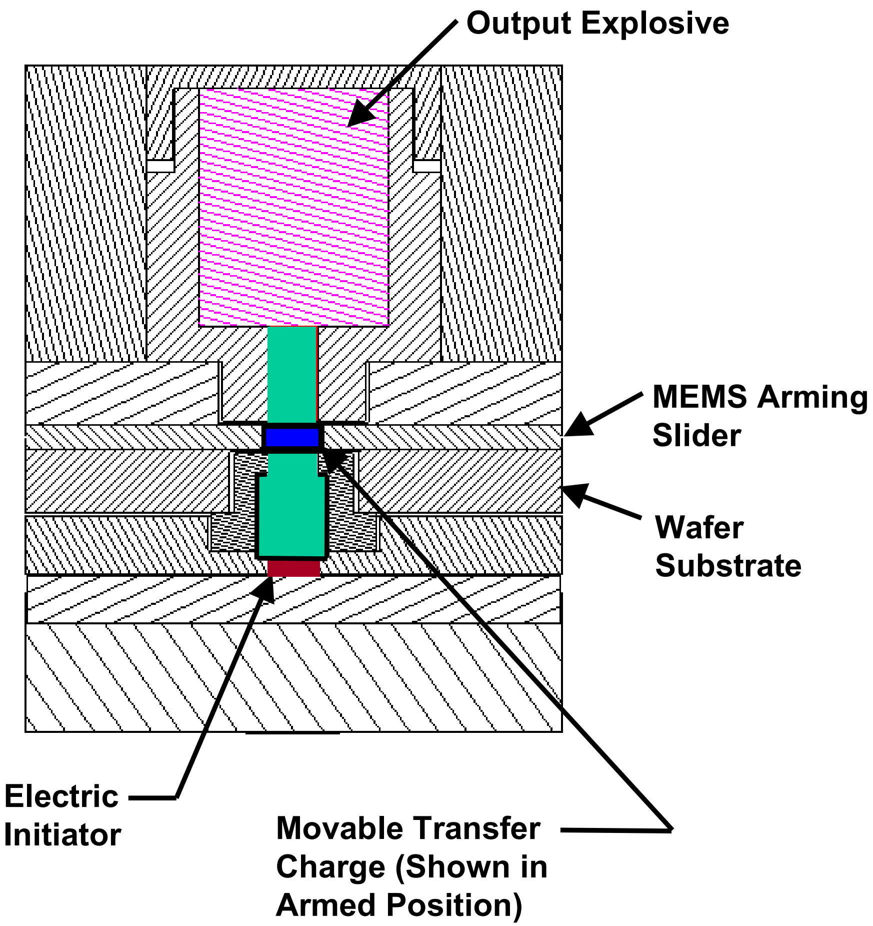
- **BAD Things About *Conventional Mechanical High-G S&As***
  - → Large parts count
  - → Pick-and-place assembly
  - → Dissimilar materials
  - → Lubrication (can denature)
  - → Miniature ‘clockworks’ (shrinking domestic industrial base)
  - → Large ‘cube’ of S&A could be used other ways



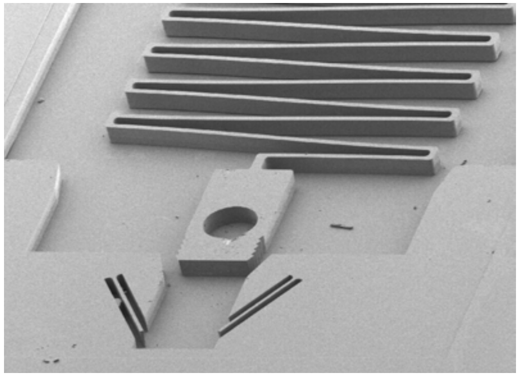
- **GOOD Things about *MEMS Mechanical High-G S&As***
  - → Moving parts fabricated ‘in situ’ (wafer level assembly)
  - → All functional parts of same material (nickel)
  - → No lubrication
  - → Commonality for use across multiple high-g applications
  - → Greatly reduced mass of lead-containing explosives in MSF



Micro-Scale Firetrain per MIL-STD-1316, and Material Selection



High Aspect Ratio

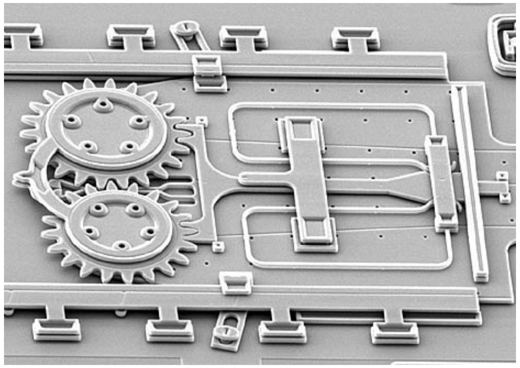


ARDEC

200-µm Nickel

Inertially-Actuated

Surface Micro-Machined



Sandia

2-µm Poly-Si

Electrically Actuated

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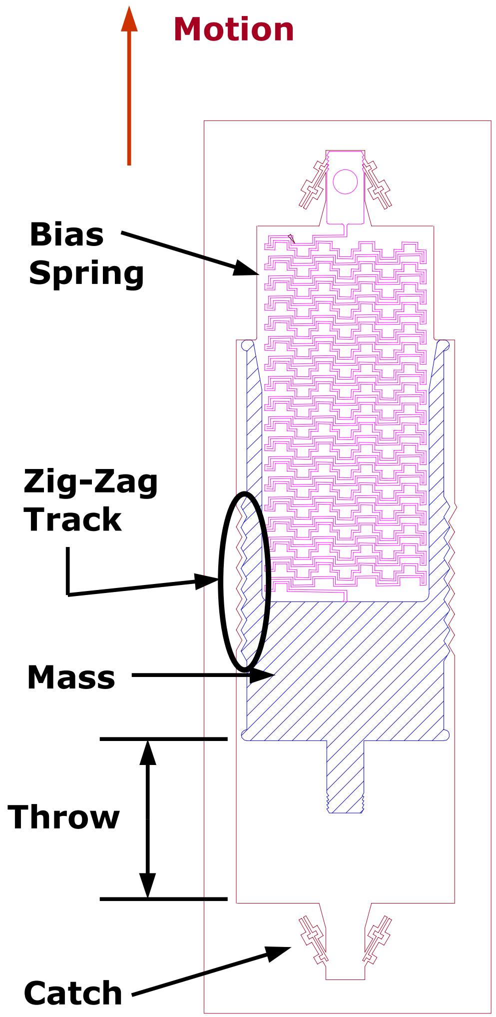
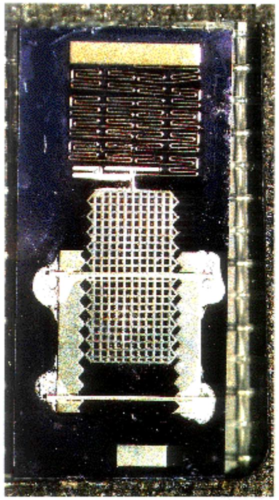
Zig Zag Inertial Delay Slider Design



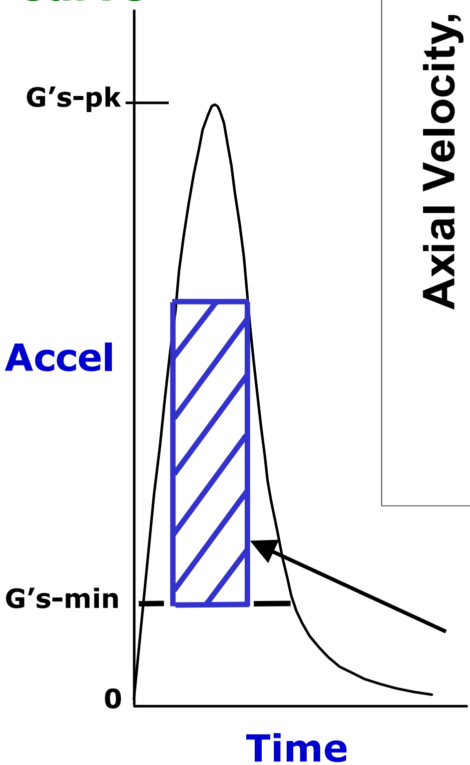
- Requirement: <u>40-ft Drop Safety</u>
- Integrates axial acceleration pulses (e.g. setback) $\rightarrow \Delta V$
- Removes first lock on MEMS arming slider
- Spring resets mass after small inputs
- Design variables:
  - $\rightarrow$ slider mass
  - $\rightarrow$ "throw" distance
  - $\rightarrow$ number of zig-zag (stop/start) "stages"
  - $\rightarrow$ rack parameters (pitch and depth)
  - $\rightarrow$ spring stiffness and bias
- First prototype demonstrated in 1996 $\longrightarrow$
- Patent no. 5,705,767

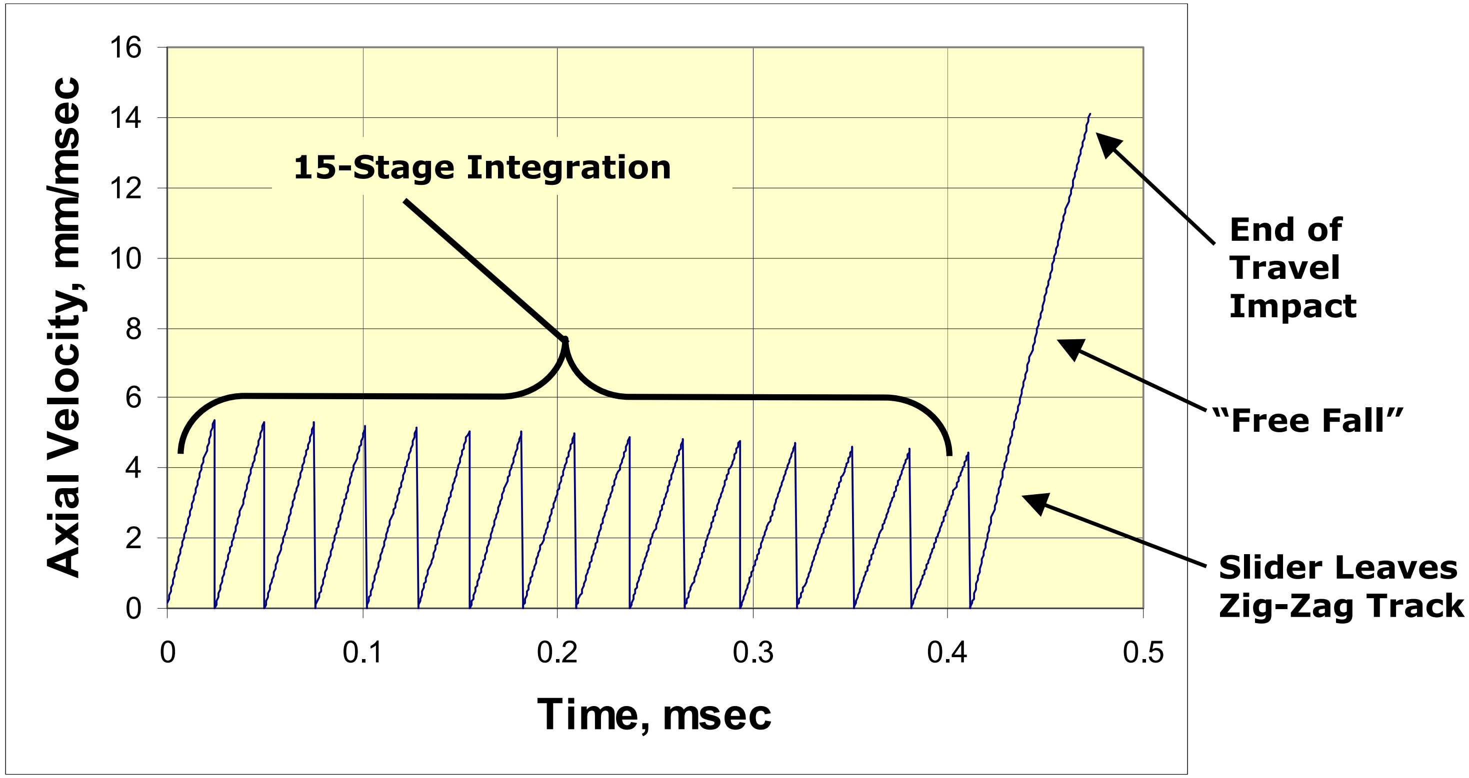


Calculated Zig-Zag Slider Motion

(Spring Pre-Bias, 45kG OICW Launch Acceleration)

Launch Acceleration Curve





ΔV = (Acceleration)(Time)

= Area Under Curve

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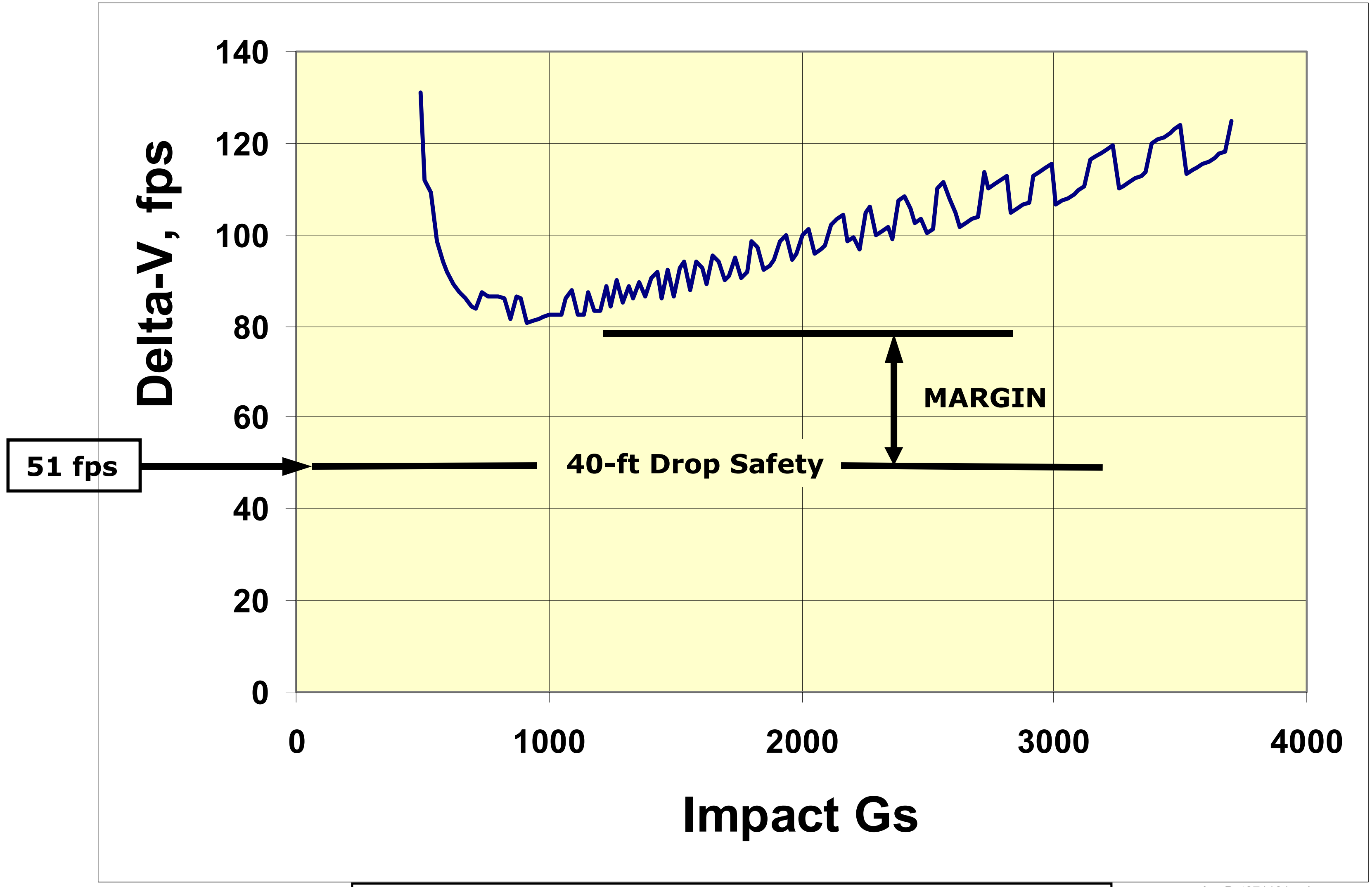
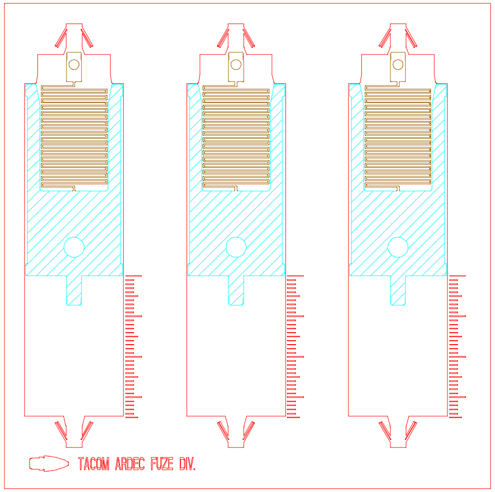
Calculated Zig-Zag Slider Arming Curve

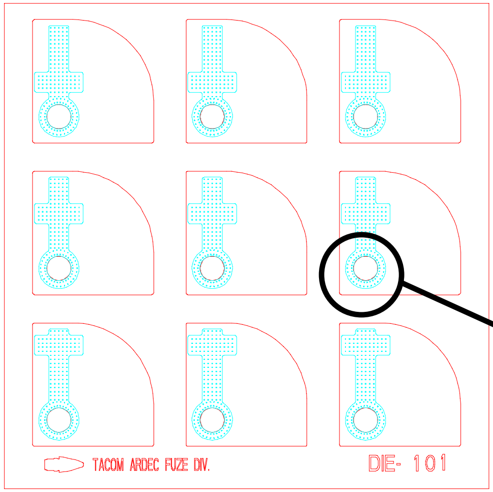


ArmDat071101a.xls

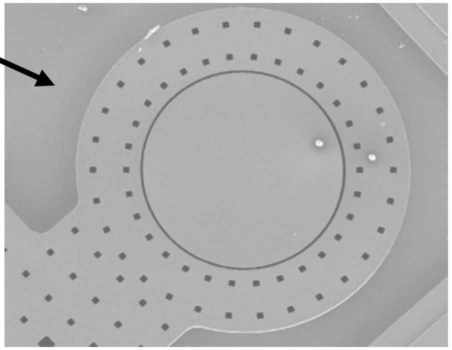
DRIE-Fabricated Silicon Structures Used to Prove out Concepts and Generate Data

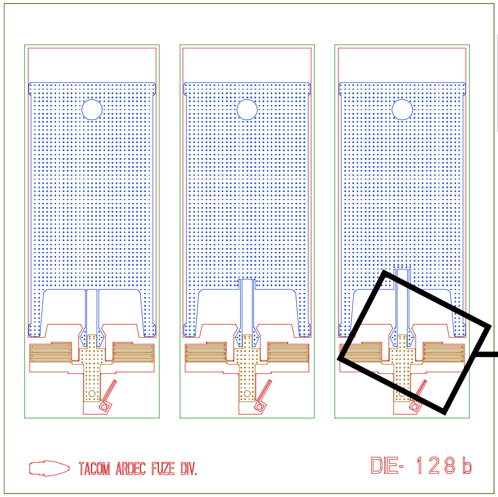


Spring/Mass with Latches

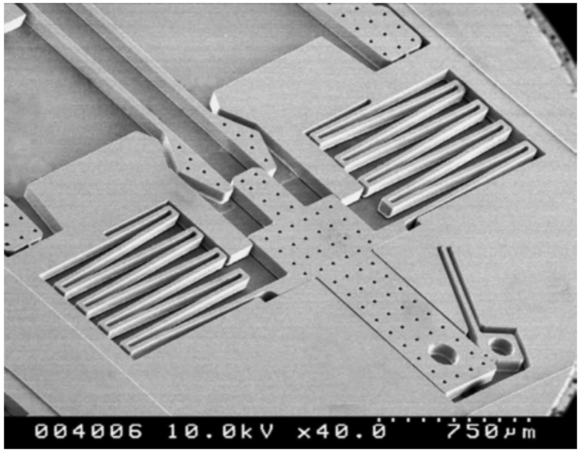


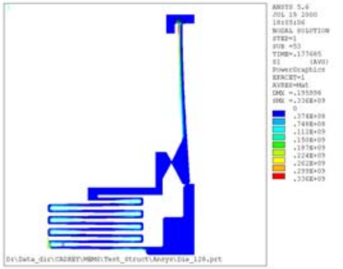
Rotors (varying radial clearance and torque)





Reversible Anchors





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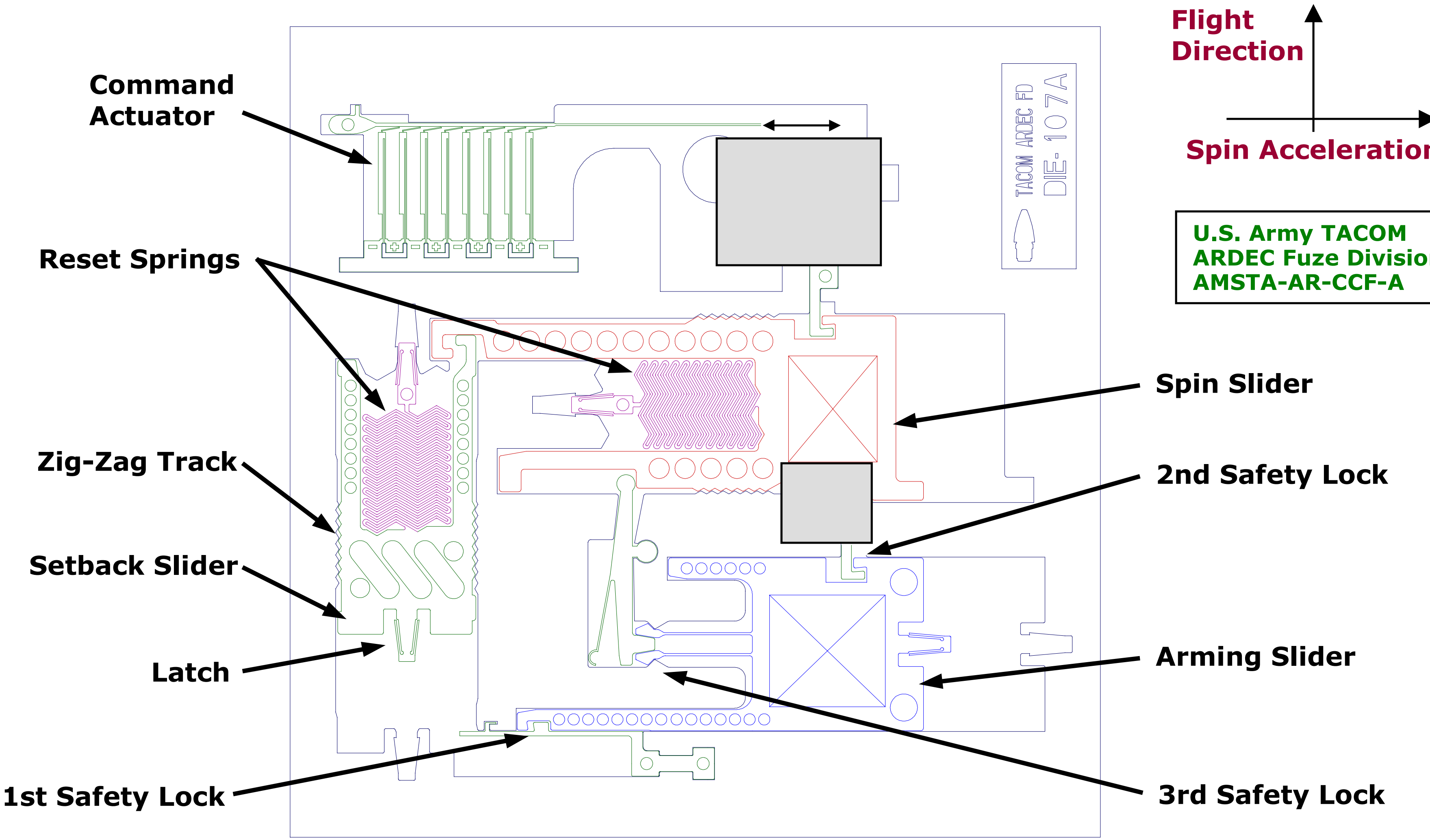
MEMS Mechanical S&A for OICW



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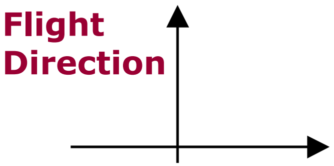
MEMS Mechanical S&A for OICW: Armed

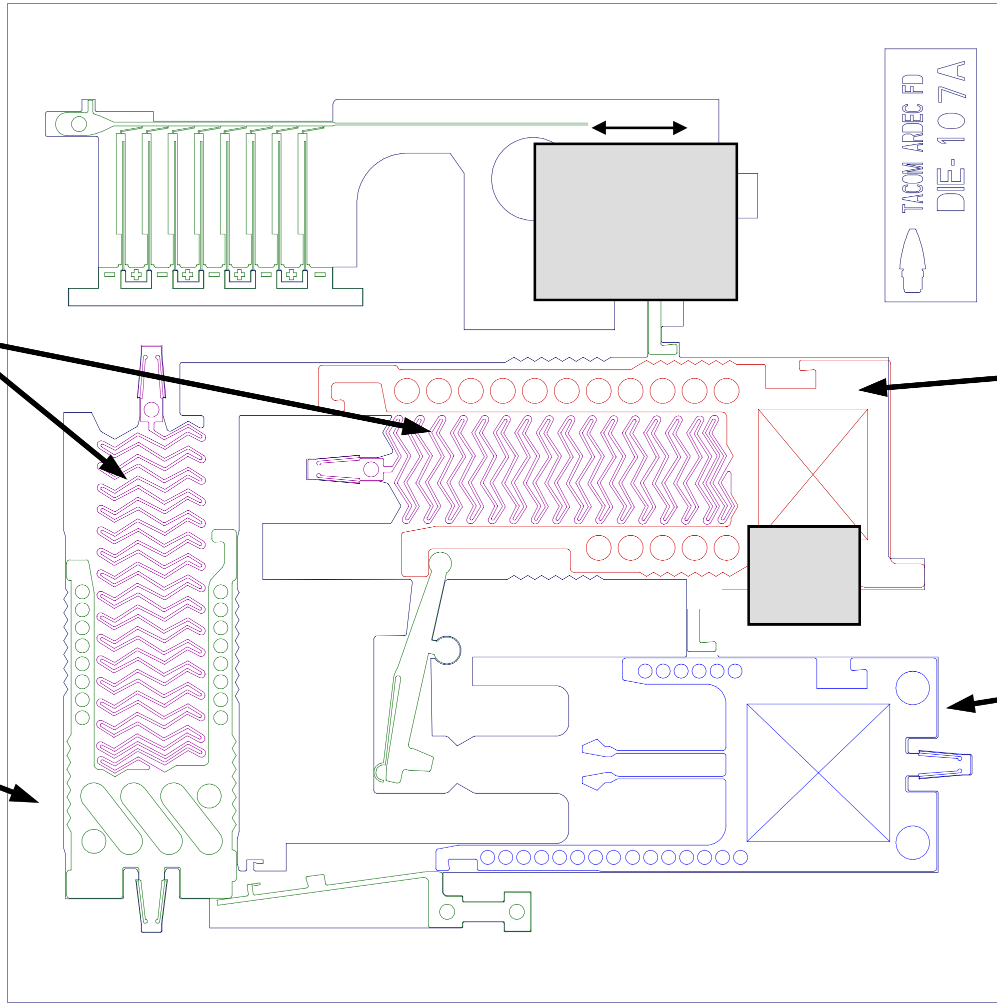


Reset Springs Under Tension

Spin Slider Deployed

Setback Slider Latched After Launch

Arming Slider Latched in Armed Position, (Fire-Train Elements Aligned)



Subject of U.S. Patents 5,705,767, 6,167,809 and Patents Pending

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Technical Issues / Challenges

Micro-Scale Firetrain (MSF)

→ Demonstrated MSF at NAWC-CL using MEMS S&A parts, June 2001

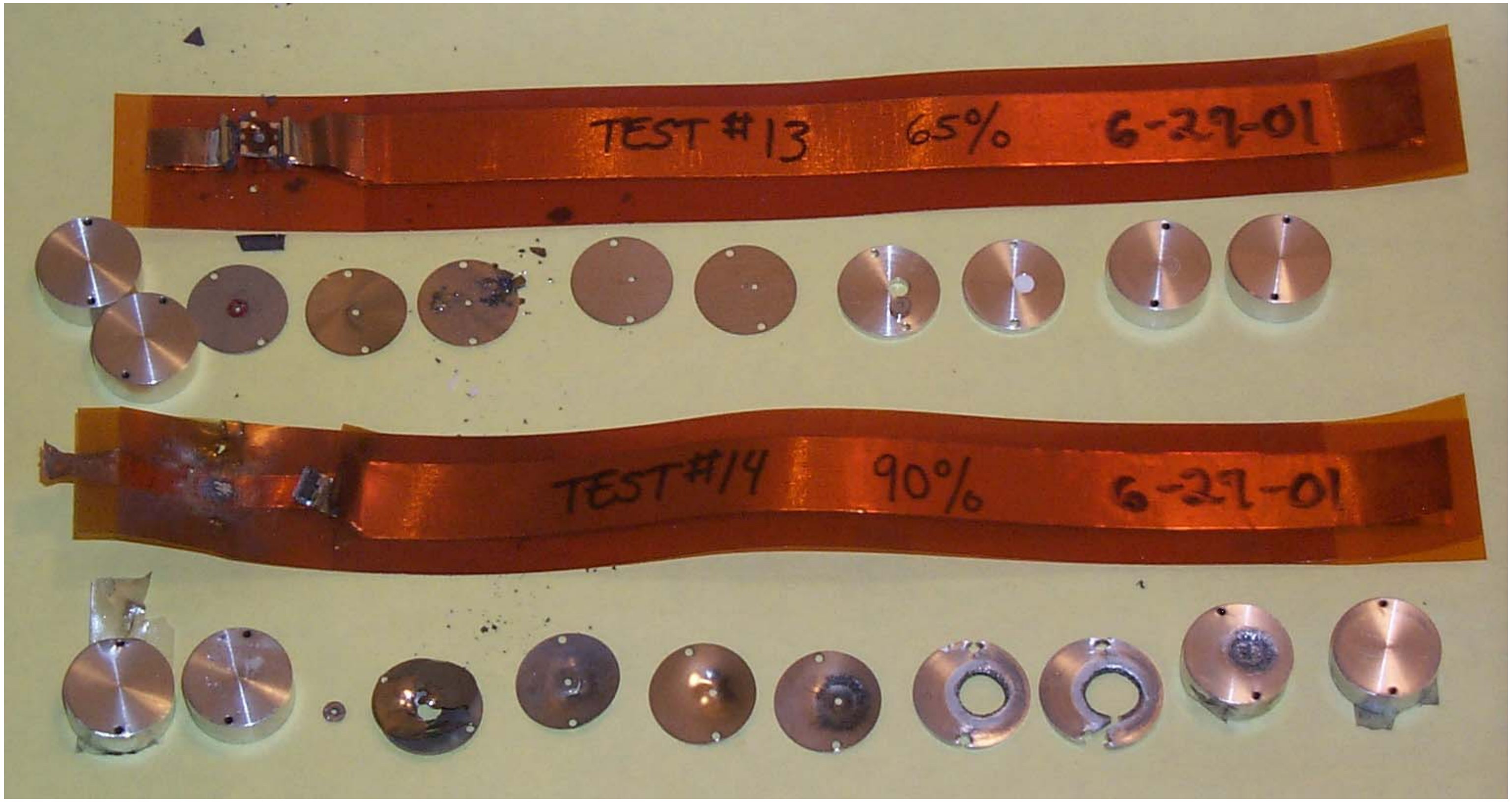
- **Test quantity was 24 units, four times that for the November '00 tests**
- **Samples distributed between safe, armed, and partially armed**
- **Obtained no detonations when in safe position**
- **Armed units detonated**
- **Partial-arming tests yielded a first cut on the 50% point (it is near 75% armed)**

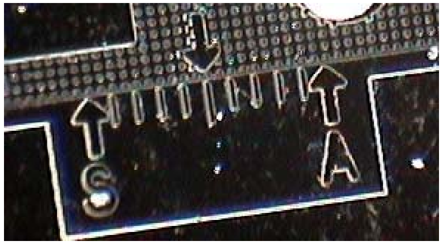
→ Next steps

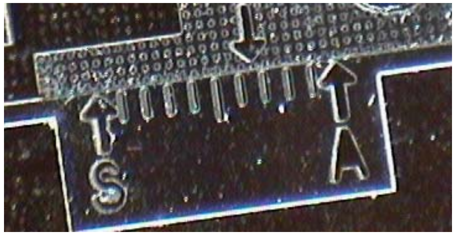
- **More firetrain demonstrations next month (Sept '01)**
- **Will be in sufficient quantities for a statistical analysis**
- **TACOM-ARDEC WECAC investigating economical explosive loading methods for MSF**

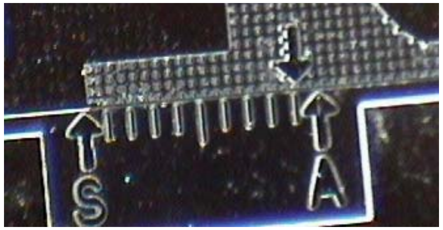
→ Environmental: *MSF* has *95% less lead-containing explosives than the* M100

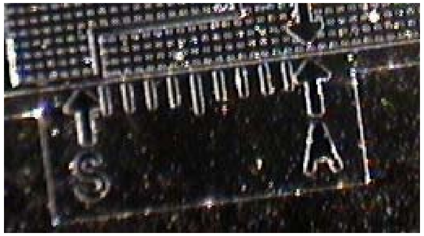
Microscale Firetrain (MSF) for MEMS S&A, Preliminary Testing, June 01











Technical Issues / Challenges

MEMS Mechanical S&A for OICW: GETTING PARTS

A. Demonstrated concepts, designs, analyses, properties of structures in *silicon*

- Defining features and implementing ‘mechanical logic” appears viable
- DRIE (silicon) parts delivery later this month, BUT…

a. Fabrication cycle time is long (~ 6 months) and yield is low (< 20%)

→ **Pursuing “massively parallel iterations,” trying many approaches at once**

b. ‘Stiction’: parts don’t release or they release and then re-adhere

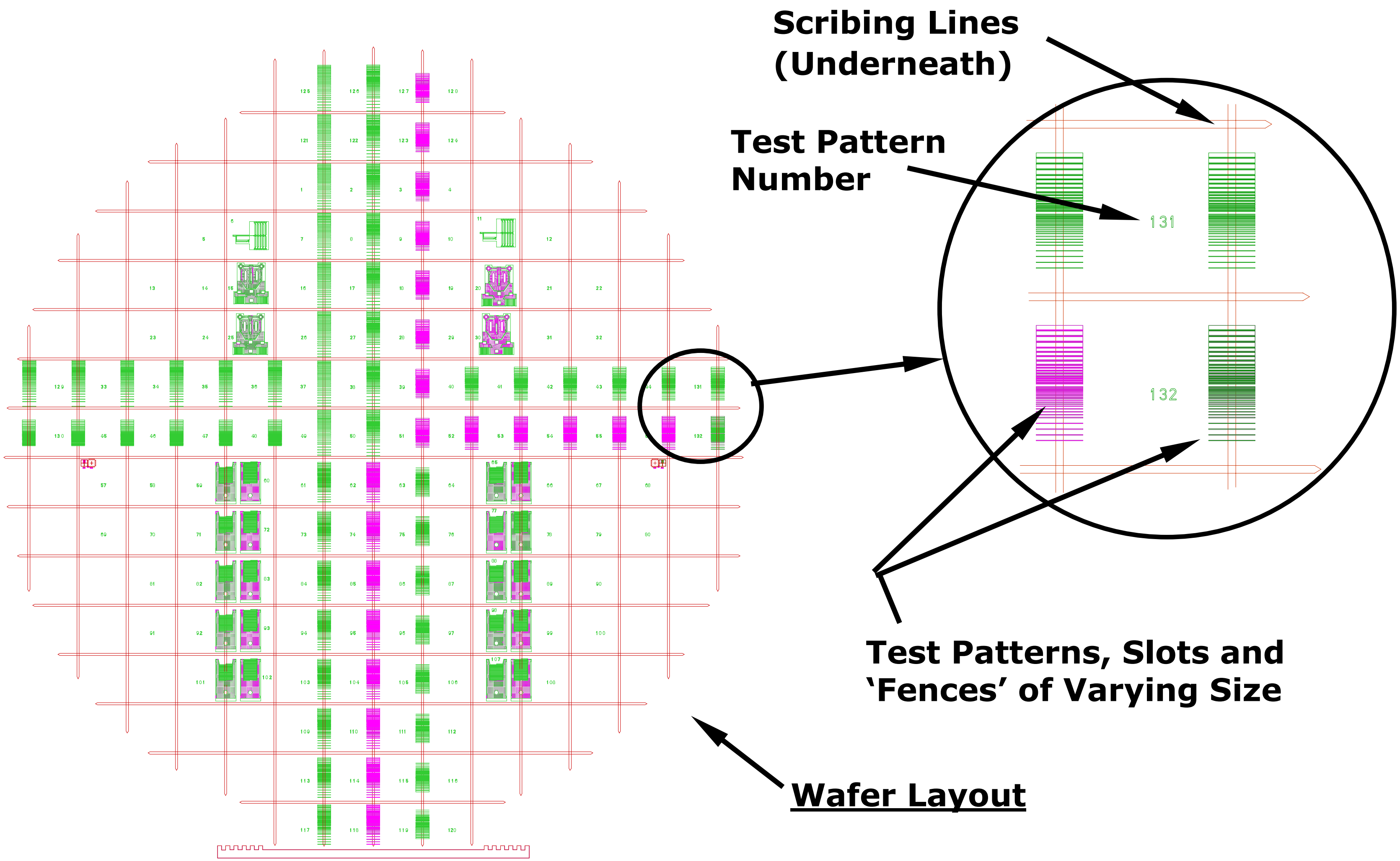
→ **Developed special process methods to avoid liquid immersion**

c. Impact testing showed silicon parts vulnerable at high strain rates

d. Silicon for demonstrating concepts, need ductile material for functional parts

continued…

Test Patterns to Investigate Silicon Deep-Etch Process Variation



Technical Issues / Challenges

MEMS Mechanical S&A for OICW: GETTING PARTS, continued

B. Next stage is move to nickel (LIGA) parts for ductility

C. Anticipate improved MEMS fabrication methods in future

- Manufacturability based on high-volume “printing” of nickel parts via LIGA “master”
- With improved firetrain can resort to well-established HAR fabrication techniques

D. Doing a MEMS S&A cost study for OICW production

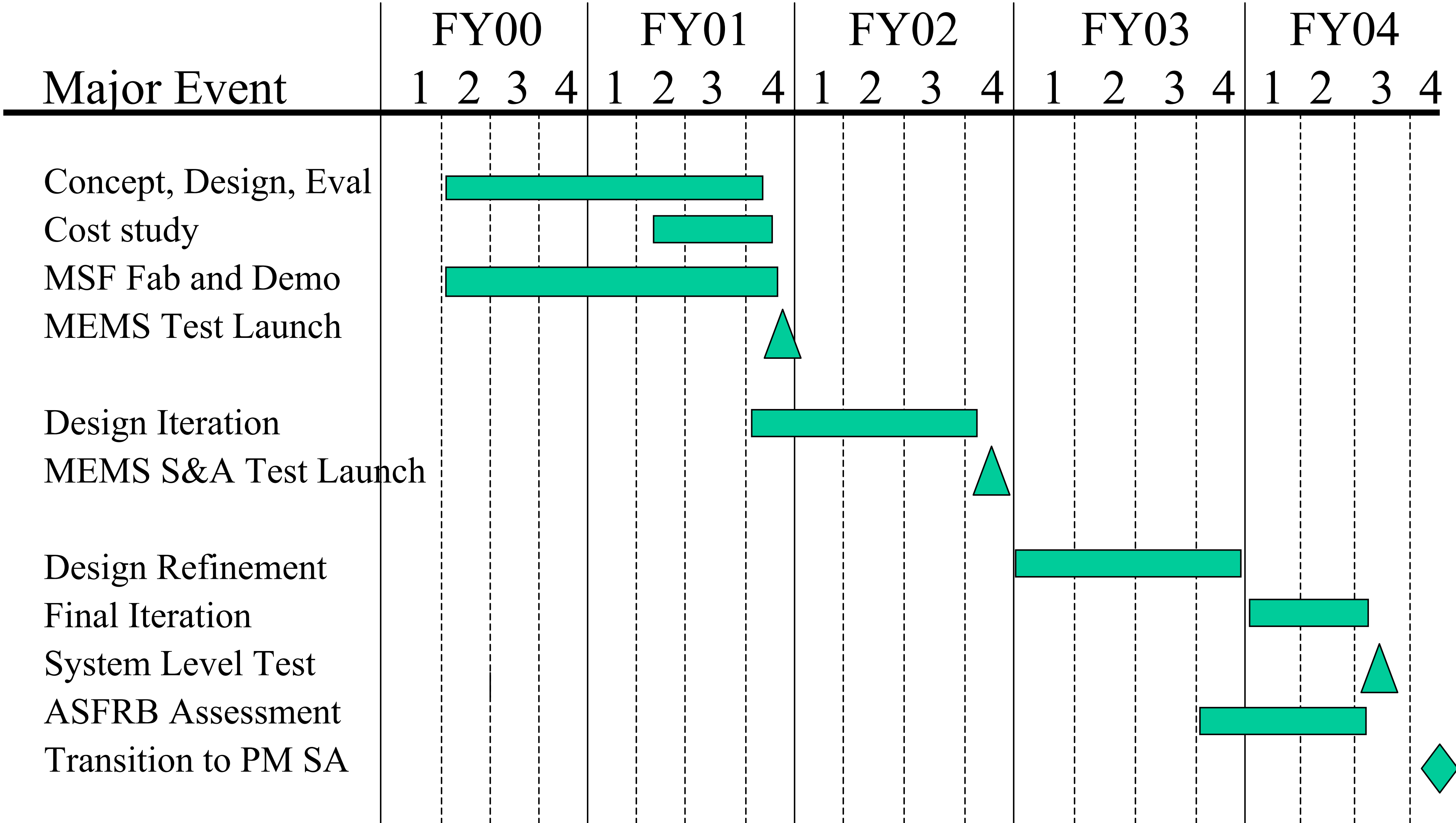
- Consulting high-throughput MEMS manufacturers
- “Assuming 10M parts using advanced MEMS technology five years from now…”
- Investigating breakthrough wafer-scale explosive loading techniques for MEMS

SUMMARY

- **MEMS - Enabling Technology for Fielding of OICW and OCSW**
  - → Meet S&A cost and volume (lethality) targets
  - → Revolutionize fuzing for small arms
- **Technology Barriers Remain:**
  - → "MEMS is an emerging technology" (M. Huff, CNRI MEMS Exchange, July 2001)
    - **New fabrication technologies still coming on line**
    - **Infrastructure is behind the demand curve…judicious prototyping**
  - → We will continue to work out the feasibility…
  - → But *the next major challenge will producibility*.

MEMS S&A for OICW

(OICW System Enhancements STO)



OICW System Enhancements

Technology Readiness Level (TRL) Maturity

FY01	FY02	FY03	FY04

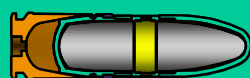
TRL=4

- Preliminary Fuze Architecture
- Demo MEMS/MEI Components in Test Barrel

METRIC

- MEMS component function & survivability – go/no go
- MEI Initiation – go/no go
- MEI out of line safety – go/no go
- Parts count to 5

TRL=5



- Army Fuze Safety Review Board
- Weapon Fire MEMS/MEI S&A

METRIC

- Demonstrate complete S&A System including MEI
- Meets the intent of MIL-STD-1316
- 75% vol reduction

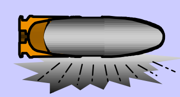
TRL=2

- Identify Direct Fragmentation Concept/ M&S

METRIC

- Assess potential for 20% increase over baseline lethality – go/no go

TRL=4

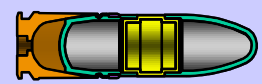


- Demo directed fragmentation

METRIC

- Arena test - Direction conical or angular – go/no go
- Exceeds PDRR baseline lethality

TRL=5



- Demonstrate Directed AB Concept in conjunction with Std OICW fuze

METRIC

- P(I) >50%

TRL=6

- Complete System Test
- Performance and Ltd Environmental Evaluation

METRIC

- Assess to MIL-STD-1316 design criteria
- Validate unit cost 50% < than $5.50
- Environmental stresses – MIL-STD-331